Drop Reliability Study of PBGA Assemblies with SAC305, SAC105 and SAC105-Ni Solder Ball on Cu-OSP and ENIG Surface Finish

W.H. Zhu[1], Luhua Xu[2], John HL Pang[2*], X.R. Zhang[1], Edith Poh[1], Y.F. Sun[2], Anthony Y.S. Sun[1], C.K. Wang[1], H.B. Tan[1]
1. United Test & Assembly Center Ltd. (UTAC), Serangoon North Ave 5, Singapore 554916
Email: wh_zhu@sg.utacgroup.com; Tel: 65-65511348, Fax: 65-65518711
2. Nanyang Technological University 50 Nanyang Avenue, Singapore 639798
Email: mhlpang@ntu.edu.sg; Tel: 65-67905514, Fax: 65-67911859

Abstract

Lead free SnAgCu solder joints used in surface mount packages like Ball Grid Array (BGA) have a great impact on the reliability of the end product. The mechanical properties of the solder are important factors. By changing the concentration of silver and copper, or by doping a very low portion of the fourth element (e.g. Ni), the strength of solder can be optimized. In this work, the board-level drop test reliability performance of different PBGA soldered assemblies with three different solder ball alloys (SAC305, SAC105 and SAC 105-Ni200ppm) and two surface finishes (Cu-OSP and NiAu) were studied. We found that SAC105-Ni showed the best impact reliability performance among the 3 types of materials, followed by SAC105 and SAC305 for either OSP or NiAu surface finish. OSP surface finish showed better drop lifetime than NiAu surface finish regardless of the type of solder used in the assemblies.

1. Introduction

Lead-free solder joint reliability research has identified certain weakness in the long-term reliability failure mechanism in soldered assemblies [1-2]. Drop impact related failures in electronic components in portable electronic products such as cell phones, PDAs and digital cameras are driving extensive research investigations [3-6]. The competitive advantage in terms of product design for reliability in lead-free soldered Integrated Circuits (IC) packages and board assemblies requires further research. Board-level drop reliability studies on Chip Scale Packages (Fine-pitch Ball Grid Array) assemblies with lead-free solders have been reported earlier [4-5]. Finite element modeling studies are useful in failure prediction of solder joint stress strain response subject to drop impact loading [6-7]. Three dominant mechanisms will affect board level drop impact failure of interconnect. The first is the bending and elongation of interconnect due to differential flexing of printed circuit board and package. The second is the large inertia force from IC package due to gravitational acceleration and the third, stress waves generated from impact. As a result, a typical impact failure is brittle fracture of IMC caused by dynamic load. To improve the impact reliability, the selection of the right board level packaging material is very important. The mechanical properties of SAC solders and the related inter-metallic compound (IMC) effects on drop related failures suggest that the solder alloy composition can affect the drop durability if the silver content (Ag) is reduced from 3.0% to 1.0% for SAC305 to SAC105 respectively. The reduction in strength in SAC105 compared to SAC305 will lower the load transfer from the solder material to the IMC interface and is anticipated to improve drop reliability. To gain further improvement on the drop durability, a fourth element reinforcement on the SAC105 solder alloy by Nickel (Ni) doping for SAC105-Ni solder alloy hold good prospects for improving drop reliability and is investigated in this study using a ball grid array (BGA) soldered assembly.

Board-level drop test reliability performance of PBGA soldered assemblies (54 I/O, 7x10 mm) with three different solder ball alloys (SAC305, SAC105 and SAC 105-Ni) and two surface finishes (Cu-OSP and NiAu) were studied by using JEDEC standard impact test method. Their drop lifetimes were compared and analyzed.

2. Experimental

2.1 Test Samples

The PBGA components and soldered PCB assembly is shown in Figure 1. There are six legs in the current study consisting of 3 types of solder ball alloys, namely SAC305, SAC105 and SAC 105-Ni that are soldered on to PCBs with 2 surface finishes, Cu-OSP and NiAu (i.e.: ENIG). The six types of test board are given in Table 1.

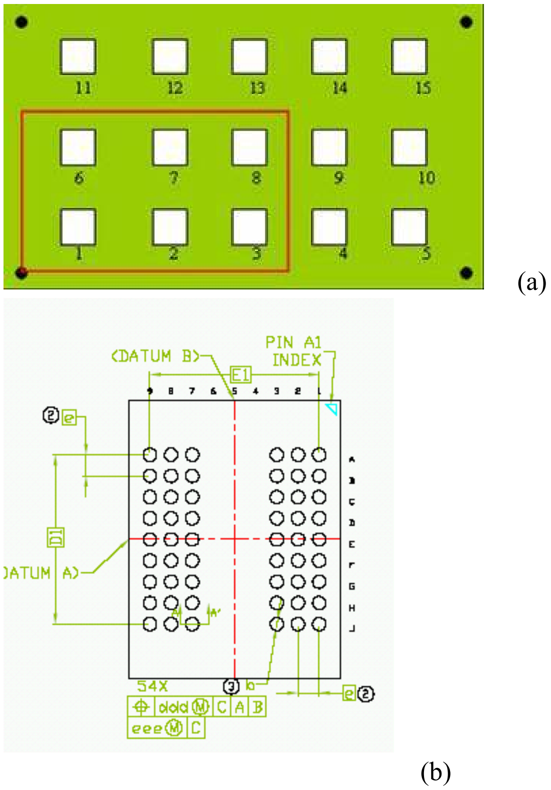

Figure 1: (a) JEDEC standard drop test board with 15 components and (b) 54 I/O PBGA component

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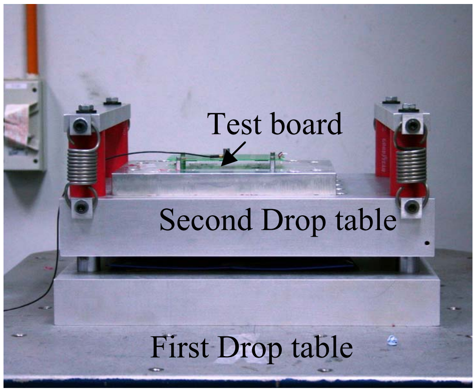
Table 1: Drop Test Boards and Test Condition

	Solder and surface finish	Test condition (5000G, 0.29ms) and boards
Leg 1	SAC105Ni-OSP	5
Leg 2	SAC105Ni-Ni/Au	5
Leg 3	SAC105-OSP	4
Leg 4	SAC105-Ni/Au	4
Leg 5	SAC305-OSP	4
Leg 6	SAC305-Ni/Au	3

2.2 Calibration of acceleration response on boards

In this study, the set input acceleration (input-G) on the test table and measured acceleration from different location (output-G) of the PC board were investigated.

In our drop test table, a two-step impact apparatus is applied, where the large drop table touches the base and generates first impact acceleration. At this moment, the small drop table supported by four springs goes down and touches the large drop table, thus generate the secondary impact acceleration, which is about 10 times higher than the first acceleration. For example, the impact acceleration can reach 1500 G in the new system when the drop height is only 20-25 cm. By varying the height and the base felt, acceleration with different G and duration can be achieved. As shown in Figure 2, the acceleration can reach 1500 g with the duration of 0.6 msec when the drop height is about 20 cm.



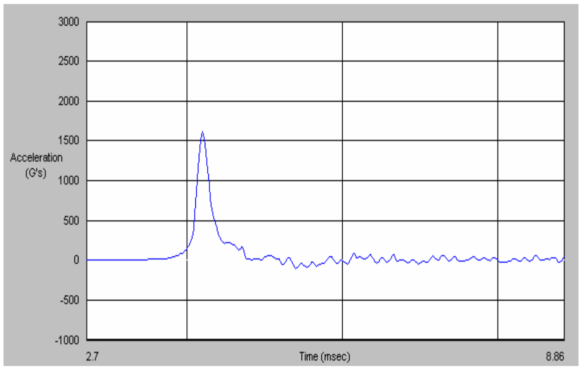


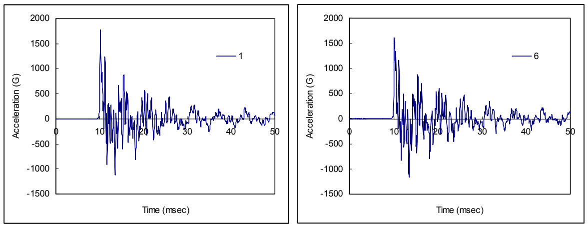
Fig 2, Input G level of 1500 G at a drop height of 20 cm.

Table 2 shows the measured peak acceleration value and the duration of input-G at different drop heights. The higher the drop height, the higher the input G, acceleration is reached.

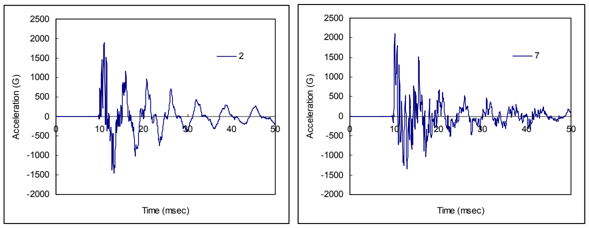
Table 2: Input-G at corresponding drop heights

Acceleration and duration	Drop height
600 G 1.1 msec	5 cm
790 G 0.64 msec	10 cm
1560 G, 0.60 msec	20 cm
2200 G, 0.51 msec	30 cm
2960 G, 0.45 msec	40 cm
4100 G, 0.40 msec	50 cm
4930 G, 0.31 msec	60 cm

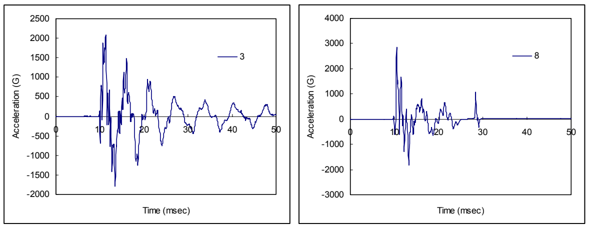
When the components are soldered on different location on the board (e.g. components 1 to 15 on the test board as shown in Fig 1), the drop performance lifetime are expected to be different and dependent of component location. This is due to the different level of resultant output-G, the bending effects of the first mode shape, and higher order mode shapes at different locations on the PCB. The output-G was measured at six locations for the JEDEC standard 4-screws support, as shown in Figure 3.



1760G, 0.8 ms 1622G 0.75 ms



1902G1.0 ms 2119G 1.0 ms



2087G, 1.0 ms 2854G, 0.7 ms

Figure 3, Output G at different locations for 1500G

It can be seen that the output-G at all the six positions are higher than the input-G (1500 G and 0.6 second). Particularly at component 3 and 8, the output-G is almost two times (2X) higher than input-G level. The larger bending effect along the longer-edge for 4-screws support has a longer impact pulse period of 100 milliseconds (msec). This larger bending deformation effect and longer pulse duration time causes more damage and earlier drop failures.

3. Results and Discussions

3.1 Drop impact reliability performance

The drop lifetime for the components at different locations was recorded. There are three solder alloys used in the test board, i.e. SAC305, SAC105 and SAC105+Ni, where the concentration of Ni is about 200ppm. In each test board, the components are categorized as six groups due to their location on the boards from A to F, as given in Figure 4.

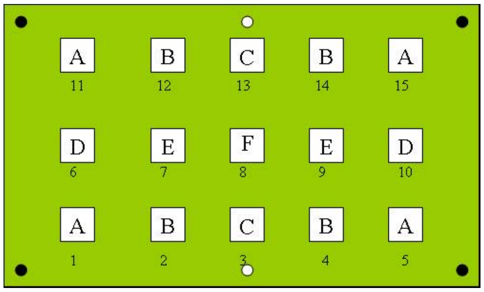


Figure 4 The components at different locations in a test board, A to F.

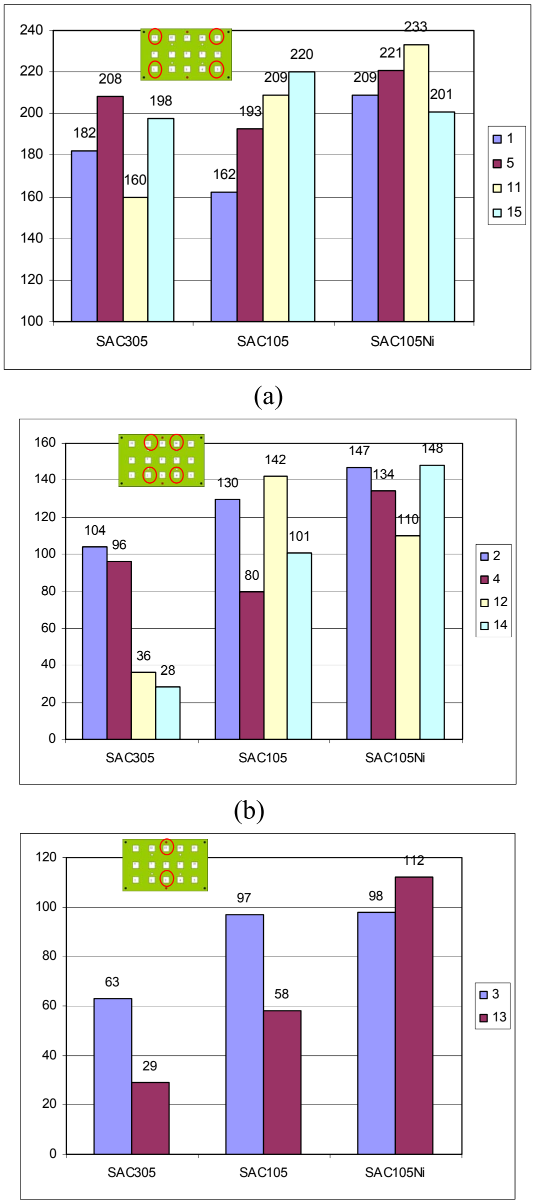
Table 3 lists the drop impact lifetime for the three solder alloys. The results listed are for OSP surface finish at the component side (i.e. Leg 1, 3 and 5). The trend of solder alloys effect is clear. SAC105-Ni has the best drop reliability, followed by SAC105 and SAC 305.

Table 3 Drop impact lifetime comparison for different solder alloy (with OSP at components side)

Component #		SAC305	SAC105	SAC105Ni
Location A	1	182	162	209
	5	208	193	221
	11	160	209	233
	15	198	220	201
Location B	2	104	130	147
	4	96	80	134
	12	36	142	110
	14	28	101	148
Location C	3	63	97	98
	13	29	58	112
Location D	6	132	171	147
	10	168	136	191
Location E	7	171	154	138
	9	132	181	194
Location F	8	144	130	170

Overall the drop lifetime for the test board with SAC105Nisolder joints (Leg 1) is 10% higher than that with SAC105 (Leg 3) and 15% higher than SAC305 (Leg 5). Table 3 also shows the location effect on the drop reliability. The components at location A, the corner components have the best performance, followed by F, E, D, B and C.

Figure 5 (a-c) shows the effect of solder alloy at three locations A, B and C. The components at different location showed different drop life-time, which is correspond to the different output-G at different locations. The effect of the three solder alloys used in this test is not straightforward from the numbers due to the deviation. However, the trend is clear by averaging the test results.



(a)

(b)

(c)

Figure 5 Drop performance comparison for different solder alloys at different location

For the corner components 1, 5, 11, and 15, the components with SAC305 solder alloy fail after 182, 208, 160 and 196 drops respectively, with an average of 187 drops. The components with SAC105 solder alloy fail after 162, 193, 209 and 220 drops respectively, with an average of 196 drops. The components with SAC105-Ni alloy fail after 209, 221, 233 and 201 drops respectively, with an average of 202.

For the drop lifetime for different solder alloy on NiAu, again the components with SAC105-Ni showed the best drop performance, followed by SAC105 and SAC305. By averaging the test data, we can see the trend of the drop impact reliability performance is: OSP surface finish is better than NiAu surface finish, and SAC105-Ni solder alloy is better than SAC105 and SAC305. Figure 6 show the performance comparison of the components with different solder and surface finish.

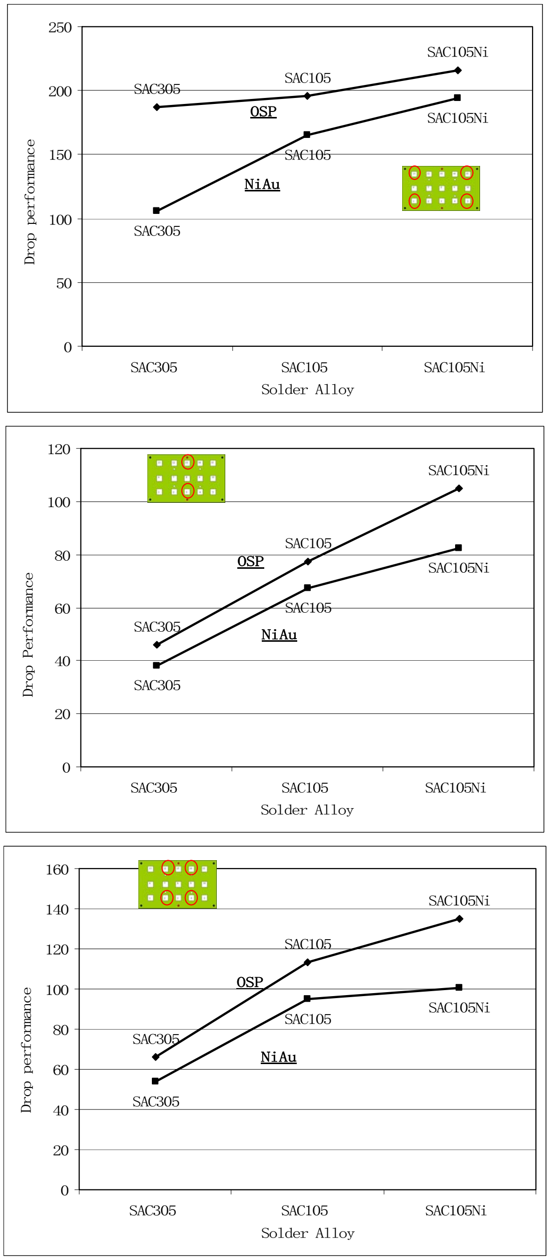
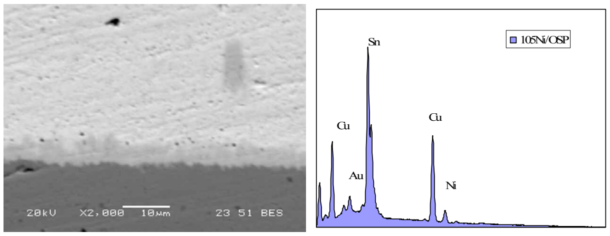


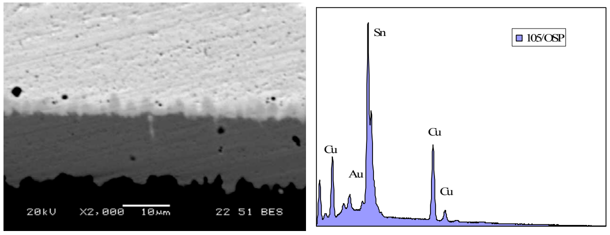
Figure 6 Drop performances for all the six types of test boards.

3.2 Solder Joint IMC structure

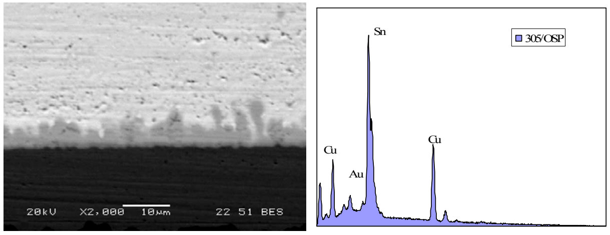
The solder joint interfacial microstructure and the mechanical properties of the solder alloy are characterized. The components contains different surface finish and solder alloy are cross-sectioned and characterized by scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) to investigate the interface structure. Figure 7 (a-c) shows the three solder alloys on OSP surface finish.



(a) SAC105Ni/OSP solder joint and EDX analysis of IMC



(b) SAC105/OSP solder joint and EDX analysis of IMC



(c) SAC305/OSP solder joint and EDX analysis of IMC

Figure 7 (a-c) SEM and EDX characterization

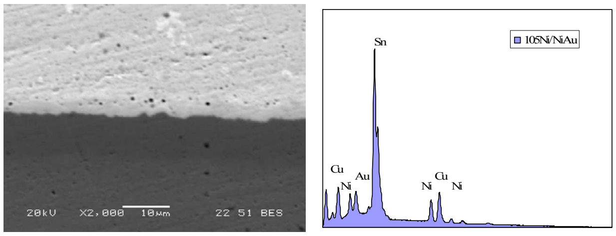
By comparing the IMC interface structure for as-reflowed sample, we can see that with Ni doping in SAC105-Ni solder alloy, the IMC thickness obtained after reflow is higher than SAC105/OSP and SAC305/OSP.

The IMC composition were characterized by precision energy dispersive X-ray (EDX). In which the element atomic ratio in the IMC can be determined. As given in Table 4. For SAC105Ni/OSP solder joint, the IMC layer at the as reflowed solder joint is $(Cu0.97Ni0.02)_6Sn_5$, where there is some Ni elements in the IMC layer. For the other two SAC alloy, the IMC layers at the interface are Cu6Sn5.

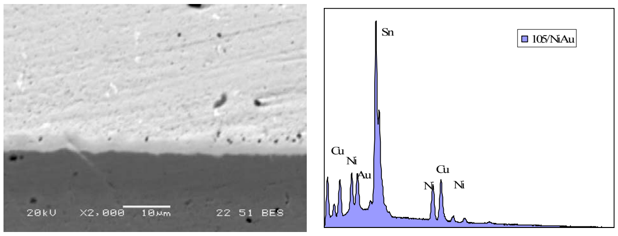
Table 4 Atomic ratio of Ni, Cu and Sn in the IMC layer (for OSP surface finish)

	Atomic ratio			IMC formula
	Ni	Cu	Sn	
SAC105-Ni	1.35	53.50	45.15	$(Cu0.97Ni0.02)_6Sn_5$
SAC105	0	54.98	45.02	Cu_6Sn_5
SAC305	0	54.77	45.23	Cu_6Sn_5

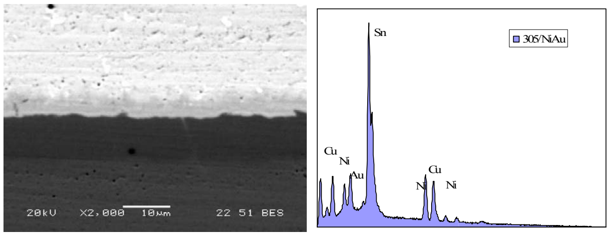
The interfacial IMC growth for solder on NiAu surface finish are characterized and compared in this section. Figure 8(a-c) shows the three solder alloys on NiAu surface finish.



(a) SAC105Ni/NiAu solder joint and EDX analysis



(b) SAC105/NiAu solder joint and EDX analysis



(c) SAC305/NiAu solder joint and EDX analysis of IMC

Figure 8 SEM and EDX analysis for solders on NiAu

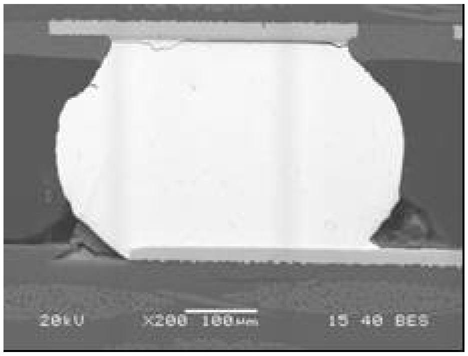
For the IMC interface structure on NiAu surface finish, the IMC layer is thinner than that in SAC/OSP solder joint. The IMC thickness is about 2.5 micron for as reflowed sample. The morphology is mainly determined by NiAu surface finish. The effect of the solder alloy is not significant for SAC105Ni, SAC105 and SAC305.

The IMC composition were characterized by precision energy dispersive X-ray (EDX). The element atomic ratio in the IMC is given in Table 5. The IMC are found to be (Cu1-xNix) 6Sn5 For all the three solder alloys on NiAu surface finish. Where the ratio of Cu and Ni in the IMC is about 3:2, Cu has much higher concentration than in the solder.

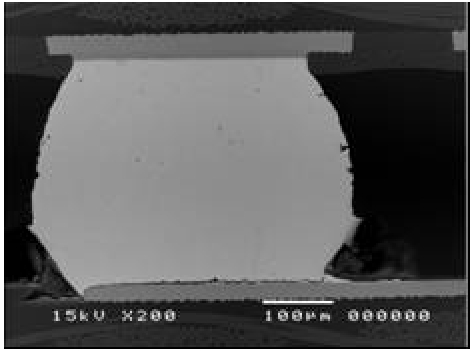
Table 5 The atomic ratio of Ni, Cu and Sn in the IMC layer (for NiAu surface finish)

	Atomic ratio			IMC composition
	Ni	Cu	Sn	
SAC105Ni	18.36	37.92	43.72	(Cu0.67Ni0.33)$_6$Sn$_5$
SAC105	22.98	33.81	43.22	(Cu0.60Ni0.40)$_6$Sn$_5$
SAC305	24.01	31.41	44.58	(Cu0.56Ni0.44)$_6$Sn$_5$

The drop impact failures were found to occur at multiple locations, which is mainly the interfacial IMC fracture at either board side or component side. Other failures were also found at the copper trace or PCB substrate. Two typical SEM images showing the IMC fracture are given in Figure 9.



(a) IMC failures at the component side



(b) IMC failures at the board side

Figure 9 Solder joint failure subjected to impact shock test

4. Conclusion

The board-level drop test reliability performance of different BGA soldered assemblies with three different solder ball alloys (SAC305, SAC105 and SAC 105-Ni200ppm) and two surface finishes (Cu-OSP and NiAu) were studied. It is found that SAC105-Ni/OSP showed the best impact reliability performance among the six types of samples, followed by SAC-105 and SAC305 for either OSP or NiAu surface finish. OSP surface finish showed better drop lifetime than NiAu surface finish regardless of the type of solder used in the assemblies. The difference in the mechanical properties of the 3 solder alloys (SAC305, SAC105 and SAC 105-Ni200ppm) and its interfacial IMC structures are areas for further research why they affect the mechanism of impact drop reliability failures and performance.

References

1. K. Zeng, R. Stierman, and K.N.Tu. J. Appl. Phys. 97, 024508 (2005)
2. T.C. Chiu, K. Zeng. Effect of thermal aging on board level drop reliability for Pb-free BGA packages, in 54th Electronic Components & Technology Conference, Vols 1 and 2, Proceedings. 2004, IEEE: New York. p. 1256-1262.
3. D.Y.R. Chong, F.X. Che, John H.L. Pang, K. Ng, J.Y.N. Tan and T.H. Low. Microelectron. Reliability, 46, p1160 (2006).
4. Desmond Y.R. Chong, F.X. Che, John H.L. Pang, L.H. Xu, B.S. Xiong, H.J. Toh1, B.K. Lim. Evaluation on

Influencing Factors of Board-level Drop Reliability for Chip Scale Packages (Fine-pitch Ball Grid Array). IEEE Transaction on Advanced Packaging, vol. 31, issue 1, February 2008.

5. Desmond Y.R. Chong, F.X. Che, L.H. Xu, H.J. Toh, John H.L. Pang, B.S. Xiong, B.K. Lim, "Performance Assessment on Board-level Drop Reliability for Chip Scale Packages (Fine-pitch BGA)", IEEE Proceedings of 2006 Electronic Components and Technology Conference, 56th ECTC, San Diego, USA.
6. Lall, P., Panchagade, D., Liu, Y., Johnson, W., Suhling, J.,Models for Reliability Prediction of Fine-Pitch BGAs and CSPs in Shock and Drop-Impact, 54th Electronic Components and Technology Conference, pp. 1296 – 1303, 2004.
7. F.X. Che, John H.L. Pang, W.H. Zhu, Wei Sun, Anthony Sun, C.K. Wang and H.B. Tan. Comprehensive Modeling of Stress-Strain Behavior for Lead-Free Solder Joints under Board-Level Drop Impact Loading Condition Electronic Components and Technology Conference 57th 2007 pp528-536.